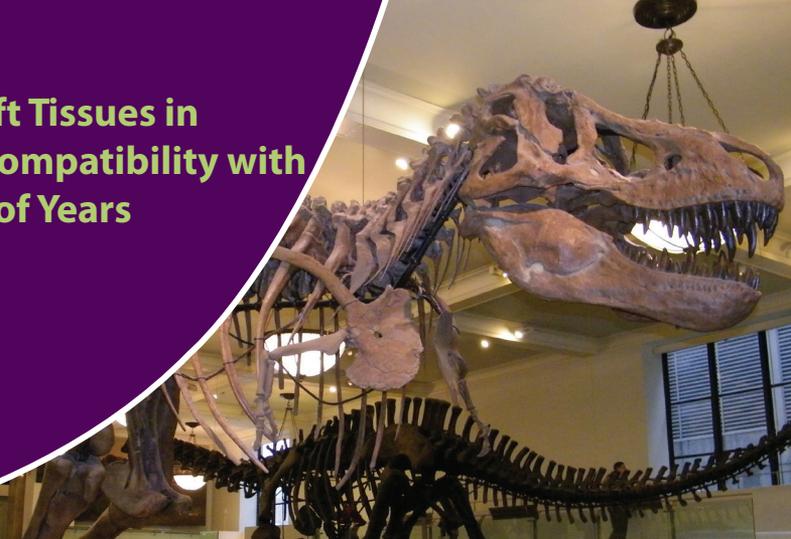


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ABSTRACT

The recent discovery of preserved cells and soft tissues in certain dinosaur bones seems incompatible with an age of millions of years, given the expectation that cells and soft tissues should have decayed away after millions of years. However, evidence from radiometric dating shows that dinosaur fossils are indeed millions of years old. Under certain circumstances, cells and soft tissues in bone are protected from complete disintegration. Formation of a mineral concretion around a bone protects biomolecules inside it from hydrolysis by groundwater. Infusion and coating with iron and iron compounds at a critical point in the decay process protects cells within a bone from autolysis. Cross-linking and association with bone mineral surfaces furnish added protection to collagen fibers in a bone. These protective factors can result in soft-tissue preservation that lasts millions of years. It would benefit educators to be aware of these phenomena, in order to better advise students whose acceptance of biological evolution has been challenged by young-Earth creationist arguments that are based on soft tissues in dinosaur fossils.

Key Words: dinosaurs, creationism, soft tissue, collagen, fossilization, hydrolysis.

○ Introduction

The recent discovery of preserved cells and soft tissues in dinosaur fossils seems incompatible with the passage of millions of years. Taking advantage of the popularity of dinosaurs, young-Earth creationist (YEC) authors now proclaim, in an ever-increasing number of books and DVDs, that preserved biomolecules and soft tissues in dinosaur fossils demonstrate that the dinosaur fossils must be only thousands, not millions, of years old (Armitage, 2001, 2015, 2017; Allen, 2005; Wieland & Menton, 2005; Ham, 2006; Hamp, 2007; Batten, 2008; Catchpoole, 2008; Lyons & Butt, 2008; Malone, 2009; Oard, 2009, 2011; Wieland, 2009; Isaacs, 2010a, b; Woetzel, 2012; Sarfati, 2013; Thomas,

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2013, 2014, 2019; Anderson, 2015, 2018; Clarey, 2015; DeMassa & Boudreaux, 2015; Institute for Creation Research, 2015; Stout, 2015; Creation Ministries International, 2017; Creation Research Society, 2017; Anonymous, 2020). That assertion is incorrect. Radiometric dating of Mesozoic strata shows that the sediments that entomb Mesozoic fossils are between 66 million and 252 million years old (Kamo et al., 2003; Ogg, 2004a, b; Ogg et al., 2004, 2016; Renne et al., 2013).

So how is it that some of those fossils contain preserved cells and soft tissues? The answer to that question currently exists mainly as a long series of technical articles in primary scientific literature, without a summary review or a specific set of responses to YEC distortions, and an internet search for answers mostly conjures a mixture of websites that barely scratch the surface of the topic and websites that promote YEC distortions. It is therefore difficult to find the needed information without spending hours wading through sources that are insufficient, misinformed, or highly technical and narrowly focused. To remedy this, I present here a review of the pertinent literature, so as to arm science educators and their students with the information they need to recognize YEC misinterpretations of dinosaur soft tissue as incorrect.

○ Preservation of Cells & Soft Tissues

Examples from Mesozoic Fossils

Cells and soft tissues rarely fossilize. They usually decay, so the remains of ancient animals usually consist only of mineralized body parts (e.g., bones and shells). When soft parts are preserved, they are usually heavily altered by chemical changes, and often what is now present is not the original set of biomolecules but a mineralized replica that preserves the shape of the soft-tissue structures that it has encrusted or replaced (Martill, 1988; Briggs, 2003).

It was therefore big news when, in 2005, a paleontological team described pockets of extraordinarily intact soft-tissue structures in a skeleton of the theropod dinosaur *Tyrannosaurus rex*. After the team demineralized part of the femur, what was left included pliable blood vessels and osteocytes (bone cells) with nuclei. In the same article, the team reported that they were able to replicate the results and isolate osteocytes and pliable blood vessels from bones of two more tyrannosaurid specimens and a hadrosaurid dinosaur (Schweitzer et al., 2005). Since then, osteocytes and pliable (after demineralization) soft tissues have been found in bone from several other Cretaceous dinosaur specimens (Schweitzer et al., 2007, 2009; Armitage & Anderson, 2013; Ullman et al., 2019; Boatman et al., 2020), in addition to bone from the Cretaceous mosasaur *Prognathodon* (Lindgren et al., 2011), the Triassic marine reptiles *Nothosaurus* and *Protanystropheus* (Surmik et al., 2016), and a few bones from the Permian Period of the Paleozoic Era (Kisleva et al., 2019).

When a 2008 study found evidence of recent bacterial biofilms in Mesozoic dinosaur bone, its authors suggested that the putative blood vessels and cells in Mesozoic bone were actually more bacterial biofilms that had been misidentified (Kaye et al., 2008). However, several subsequent studies presented chemical, immunological, and morphological data that demonstrated that the putative blood vessels and cells in Mesozoic dinosaur bone were indeed blood vessels and cells and could not be bacterial biofilms (Schweitzer et al., 2009, 2013b, 2016; Lindgren et al., 2011; Surmik et al., 2016).

In addition to the cells and soft tissues, fragments of endogenous proteins have been identified in bone from several dinosaurs and other Mesozoic reptiles, including fragments that are identifiable more specifically as the protein collagen (Gurley et al., 1991; Schweitzer et al., 1997, 2009; Embery et al., 2003; Asara et al., 2007; Lindgren et al., 2011; San Antonio et al., 2011; Armitage & Anderson, 2013; Bertazzo et al., 2015; Surmik et al., 2016; Boatman et al., 2020).

Preservation Mechanisms within Bone

The above are exciting findings, because cellular preservation is rare in fossils and was previously unknown in dinosaur fossils. So how did the cells and blood vessels escape complete disintegration in the special cases listed above? Experimental studies indicate that the pockets of extraordinary preservation in the bones in question were the happy recipients of special circumstances that allowed the operation of a previously unknown preservation mechanism involving iron and oxygen. Previous studies reviewed by Schweitzer et al. (2007) had already determined that (1) intimate association with bone minerals can keep osteocytes intact for extended periods; (2) the iron-containing heme group in hemoglobin and myoglobin inhibits breakdown by enzymes and thus can inhibit autolysis (the breakdown of a dying cell by its own enzymes); and (3) unstable metal ions catalyze the formation of oxygen free radicals, which cause chain reactions that forge irreversible cross-linkages between organic molecules and thereby prevent complete breakdown of those organic molecules. Schweitzer et al. (2007) incorporated those findings into a hypothesis of the mechanism that had caused the extraordinary preservation of the cells and soft tissues that they had found in fossils. Their hypothesis was that postmortem degradation of hemoglobin and myoglobin had liberated heme, the iron on which then became oxidized, liberating electrons, which then reacted with O_2 to produce free radicals and reactive oxygen species that formed iron-oxygen complexes with free iron that was released by the breakdown of certain organic molecules. The oxygen radicals and iron-oxygen complexes formed cross-links between lipids

in cell membranes and between other organic molecules, making them inert to further reactions and therefore stable. In short, the interaction between oxygen and the iron in hemoglobin had created iron oxides that acted as a protective coating and stabilizer for organic molecules, shielding them from complete decomposition by bacteria, fungi, and the body's own enzymes.

The results of subsequent studies supported the hypothesis. Two studies confirmed that the cross-links in Mesozoic bone collagen were iron-mediated and showed that the outer and inner surfaces of preserved blood vessels in fossil bone were coated in iron oxides, including goethite ($FeO(OH)$) and hematite (Fe_2O_3) (Surmik et al., 2016; Boatman et al., 2020). Further studies confirmed that the Mesozoic blood vessels were impregnated with iron-rich nanoparticles and that the cells and intracellular contents were impregnated with iron (Schweitzer et al., 2013b; Boatman et al., 2020). One of those studies also demonstrated that the preservation of the proteins actin and elastin in the dinosaur tissues involved being coated with iron compounds, because iron removal by chelation dramatically increased the vigor with which anti-actin and anti-elastin antibodies reacted with the tissues (Schweitzer et al., 2013b). The same study showed that treatment with hemoglobin kept ostrich blood vessels intact (including the continued presence of red blood cells and of nuclei in the cells of blood vessel walls) for the two-year duration of the study, whereas ostrich blood vessels untreated with hemoglobin decayed normally and were invaded by bacteria and fungi. Hemoglobin-treated vessels that were further treated with oxygen were even more intact (lacking any areas of collapse) than those treated with hemoglobin alone (Schweitzer et al., 2013b). Those data demonstrated the roles of iron and oxygen in long-term tissue preservation.

In addition, the identification of the mineral goethite ($FeO(OH)$) among the protective iron compounds suggested that hemoglobin was not the only protein involved but that ferritin also played a role. The intracellular protein ferritin stores iron (thereby protecting the body from iron deficiency) and releases it in a controlled manner (thereby protecting the body from being poisoned by too much free iron at once). As less-stable proteins release iron during decay, ferritin captures the iron and converts it into minerals, including goethite. The presence of goethite in the dinosaur tissues therefore suggests that ferritin contributed to their preservation (Schweitzer et al., 2013b).

The study of the iron-and-oxygen mechanism is still in its early stages. The evidence indicates that it facilitated long-term preservation of the cells and soft tissues in the fossil bone in question, but there are some important questions that have not yet been answered. For example, researchers have not yet determined how it is that the iron-and-oxygen mechanism occurred in some fossil bones but not others. A second unanswered question is whether there is a second protective mechanism that must accompany or follow the iron-and-oxygen mechanism to ensure its continued success through geologic time.

If a second mechanism is needed, phosphatization is a plausible candidate (Schweitzer et al., 2007). In certain environments, permeation with mineral-charged water causes phosphate minerals to form in soft tissues, preserving those soft tissues in organisms that fossilize in those environments (Schweitzer et al., 2007). The interior of bone can act as such an environment, because the diagenesis of bone liberates calcium phosphate from bone matrix, and it can then precipitate onto cell and tissue surfaces (Schweitzer et al., 2007). In the cases reviewed here, a postmortem coating of calcium phosphate appears to have kept the soft tissues and cells intact and stiff for millions of years. When the researchers removed it during

the demineralization of the fossil bone, the vessels and cells were restored to softness and pliability (Schweitzer et al., 2005, 2007).

External Mineral Concretions

The protein collagen is the main component of the soft tissue of bone matrix (see Senter, 2020). Like other proteins, collagen is vulnerable to decay by hydrolysis and must therefore be protected from water in order to be preserved. Collagen in a buried bone cannot be protected from hydrolysis via groundwater if the groundwater has a chance to enter the bone and reach the collagen before the protective events described in the section above have a chance to occur.

What can protect a buried bone from groundwater? Under certain circumstances, a mineral concretion forms around a buried bone. Recent studies indicate that an external concretion can shield the bone from groundwater, preventing the groundwater from entering the bone. Comparisons of fossil bones with and without external mineral concretions showed that collagen was preserved in the bones with external concretions and absent in the bones without external concretions (Ullman et al., 2019, 2020). If a concretion forms around a bone after groundwater has partly penetrated the bone, collagen is lost near the surface of the bone, where groundwater has penetrated, but is preserved in the bone's unpenetrated interior (Suarez & Kohn, 2020; Ullman et al., 2020).

○ Young-Earth Creationist Distortions

YEC authors offer a different “answer” to the question of how cells and soft tissues have survived in the dinosaur bones in question: the bones are young, just thousands instead of millions of years old (Armitage, 2001, 2015, 2017; Allen, 2005; Wieland & Menton, 2005; Ham, 2006; Hamp, 2007; Batten, 2008; Catchpoole, 2008; Lyons & Butt, 2008; Malone, 2009; Oard, 2009, 2011; Wieland, 2009; Isaacs, 2010a, b; Woetzel, 2012; Sarfati, 2013; Thomas, 2013, 2014, 2019; Anderson, 2015, 2018; Clarey, 2015; DeMassa & Boudreaux, 2015; Institute for Creation Research, 2015; Stout, 2015; Creation Ministries International, 2017; Creation Research Society, 2017; Anonymous, 2020). However, that is a non-answer. Cells and blood vessels in bone can decay within a few days (Schweitzer et al., 2013b). If some mechanism of preservation can persist long enough to counteract that tendency for thousands of years, why would it not be expected to continue to persist?

It is also inaccurate to call such bones and the tissues within them “unfossilized,” as several YEC publications do (Wieland, 2005; Wieland & Menton, 2005; Ham, 2006; Oard, 2009, 2011; Isaacs, 2010a; Woetzel, 2012; Armitage, 2015; Creation Research Society, 2017). Fossilization is, by definition, long-term preservation. So to use the word *unfossilized* for the bones and their soft tissues, which unquestionably have undergone long-term preservation, makes no sense. If the bones were indeed not fossilized, they'd now be nonexistent.

A recent article by a pair of YEC authors (DeMassa & Boudreaux, 2015) presents a putative refutation of the hypothesis that the iron-and-oxygen mechanism is effective at preserving organic molecules for millions of years. However, the alleged refutation is based on the overlooking of important facts. DeMassa and Boudreaux (2015) focused on the amino acids in peptide sequences that mainstream scientists found in fragments of collagen (San Antonio et al., 2011) and other proteins (Schweitzer et al., 2013a) in preserved soft tissues of the Cretaceous dinosaurs *Tyrannosaurus rex* and *Brachylophosaurus canadensis*. DeMassa and Boudreaux (2015) note that those

sequences include the amino acids asparagine, aspartic acid, serine, tyrosine, and histidine. They note that asparagine and aspartic acid are prone to react with water to form isoasparagine and isoaspartic acid; that amino acid sequences are prone to hydrolysis where serine is; that tyrosine is prone to react with oxygen; that histidine is prone to react with hydroxide; that the dinosaur peptide sequences include amino acid pairs that are less stable than others; and that the proposed preservation mechanism via iron-mediated cross-linkages requires an aqueous environment, whereas water promotes hydrolysis of the unstable amino acids and amino acid pairs. They concluded that the presence of those amino acids and amino acid pairs in the dinosaur peptide sequences demonstrates that the bones are young, because in their view, the unstable amino acids and amino acid pairs could not have avoided reacting with water, oxygen, and hydroxide for millions of years.

That conclusion is opposed by three important facts that are pointed out in the very references that DeMassa and Boudreaux (2015) cite: Robinson & Robinson (1991), Cournoyer et al. (2005), Catak et al. (2009), Bartesaghi et al. (2010), San Antonio et al. (2011), and Schweitzer et al. (2013a). (1) Although some individual amino acids and amino acid pairs may be more unstable than others, the longer amino acid sequences that include those amino acids and pairs can counteract those instabilities. As a result, the three-dimensional structure of a protein can protect it (at least for a time) from the reactions that DeMassa and Boudreaux (2015) list, even in an aqueous environment (e.g., within cells; Robinson & Robinson, 1991; Cournoyer et al., 2005; Catak et al., 2009; Bartesaghi et al., 2010). (2) As San Antonio et al. (2011) note, the specific amino acid sequences that they found in dinosaur collagen fragments are sequences that confer stability, are hydrophobic (and therefore prevent hydrolysis by conferring protection from water), and are shielded from external influence by tight molecular packing. Therefore, they are sequences with built-in protection against the vulnerabilities that DeMassa and Boudreaux (2015) identified. (3) The amino acid sequences that Schweitzer et al. (2013a) found were from within osteocytes, which – by virtue of their location within a protective wall of bone mineral – are naturally shielded from attack by external water, oxygen, and so on, as Schweitzer et al. (2013a) note.

○ Conclusions

Mesozoic dinosaur bones are millions of years old, as demonstrated by radiometric dating. The preservation of bone cells and soft tissues in the few Mesozoic skeletons that exhibit such preservation is due to a protective infusion and coating of iron and iron oxides during the breakdown of hemoglobin and ferritin, along with the subsequent protection that the surrounding bone mineral provides. If an external concretion is present, it further facilitates such preservation. Experimental evidence shows that the iron-and-oxygen mechanism results in long-term preservation of bone cells and soft tissues, and analyses of the Mesozoic fossils in question indicate that it took place in them. Young age does not explain such preservation, and YEC objections to old age (millions of years) are based on distortions.

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